Space Mission Architecture Trade off Based on Stakeholder Value

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Abstract. One the most difficult aspects of system conceptualization process is to recognize, understand and manage the trade-offs in a way that maximizes the success of the product. This is particularly important for space projects. In this way, a major part of the system engineer's role is to provide information that the system manager can use to make the right decisions. This includes identification of alternative architectures and characterization of those elements in a way that helps managers to find out, among the alternatives, a design that provides a better combination of the various technical areas involved in the design. Space mission architecture consists of a broad system concept which is the most fundamental statement of how the mission will be carried out and satisfy the stakeholders. The architecture development process starts with the stakeholder analysis which enables the identification of the decision drivers, then, the requirements are analysed for elaborationg the system concept. Effectiveness parameters such as performance, cost, risk and schedule are the outcomes of the stakeholder analysis which are labelled as decision drivers to be used in a trade off process to improve the managerial mission decisions. Thus, the proposal presented herein provides a means for innovating the mission design process by identifying drivers through stakeholder analysis and use them in a trade off process to obtain the stakeholder satisfaction with effectiveness parameters .

Keywords. Space mission architecture, Trade off, Value, Stakeholders, Decision

1 Introduction

An effective system must provide a particular kind of balance among critical parameters. An ideal solution should meet high performance requirements on a cost effective way in all technological areas. This is a very difficult goal to attain because the success in one area could drive a failure in other.

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Essentially all space projects go through mission evaluation and analysis stages many times; however there are relatively few discussions in the literature that tackles trade off analysis for designing cost effective architectures. [3].

Thus, considering that about 80% of the life cycle cost, performance, risk and schedule of a project are committed by decisions made during design concept exploration; this paper addresses several questions such as: how to improve such decisions? How to evaluate system architecture through cost, performance, risk and schedule by taking into account stakeholder values? How to anticipate such evaluation to the beginning of design process? How establish the connection between stakeholder values with the architecture elements? These questions do reflect the state of art of the design process regarding to concept phase.

An innovative method is proposed in this paper that is intended for investigating the system trade-off space at an early design phase taking into account all these questions stated above.

2 Concept Exploration and Systems Engineering

Project planning for space products is usually structured into sequential phases. The start up of a new phase depends generally on a milestone to be met. Usually, a project is broken down into seven or six phases according to the NASA or ESA approaches, respectively.

The initial design activity performed by "Advanced Projects" teams consists of inventing, creating, concocting and/or devising a broad spectrum of ideas and alternatives for missions where new projects (programs) could be selected from [6]. Typically, this activity consists of loosely structured examinations of new ideas, usually without central control and mostly oriented towards small studies. Its major product is a stream of suggested projects based on needs capabilities, priorities and resources. The team's effort focuses also on analyzing the project space and establishing a mission architecture.

The realization of a system over its life cycle results from a sequence of decisions among several courses of action. If the alternative actions are well differentiated in the effectiveness space, then the system manager can make choices with confidence.

The objective of systems engineering is to derive, develop and verify a life cycle balanced solution that satisfy stakeholders requirements [evolved from 2]. Stakeholders requirements are expressed in terms of performance, cost, schedule, and risk requirements which represents system effectiveness.

Thus, design trade studies become an important part of the systems engineering process. When the starting point of a design trade study is inside one envelope, there are alternatives that reduce costs without decreasing any aspect of effectiveness or increase some aspects of effectiveness without decreasing others and without increasing costs. Then, the system manager's or system engineer's decision is easy. When the alternatives in a design trade study, however, require trading cost for effectiveness, or even one dimension of effectiveness for another at the same cost, the decisions become harder. In this context, risk and schedule behave like a kind of cost [6]. This is a dillema for system engineers.

3 Integrated Mission Architecture Trade off

Systems exist to generate value for their stakeholders. Unfortunately, this ideal is often met only to a limited degree. Usually, the system manager must choose among designs that differ in terms of numerous value attributes. Often, however, the attributes seem to be truly incommensurate; managers must make their decisions in spite of this multiplicity.

At the beginning, trade studies start with an assessment of how well each of the design alternatives meets the system effectiveness (performance, cost, schedule, and risk). The ability to perform these studies is enhanced by the development of system models that relate the decision drivers to those assessments. Figure 1 shows the integrated mission architecture trade off process in simple terms.

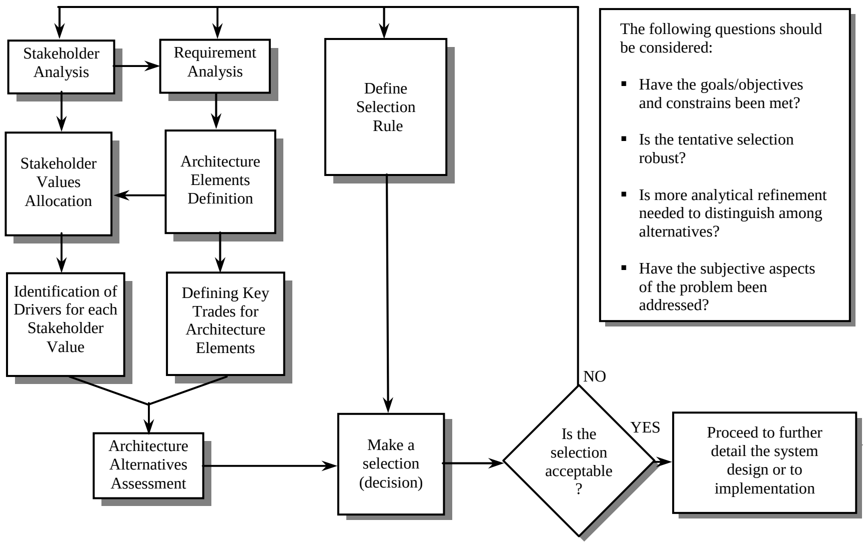


Figure 1. Integrated mission architecture trade off process

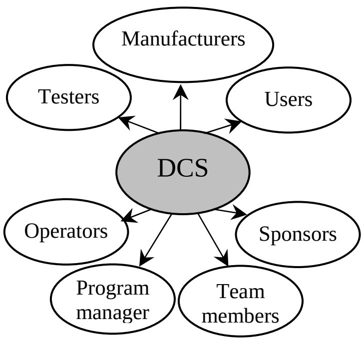
The process begins with the stakeholder analysis where it is defined all interests towards the system to be developed. The requirement analysis can be done in the same feedback loop as stakeholder analysis. Then, architecture elements can be defined and the stakeholder values (defined earlier) allocated to them. This step assures a relationship between stakeholder interests (values) and architecture elements. The definition of key trades for each architecture elements is a creative step where a set of cost effective solutions can be found. The critical point of this approach is to identify the decision driver for each architecture element and stakeholder value. Then, the method establishes a connection between physical solution and the associated aspects that can commit cost, performance, risk and schedule in a project. Comprising all these steps, the evaluation of architecture alternatives can be done, assessing element impact on architecture taking into account decision driver (performance, cost, risk and schedule) identified earlier. A set of alternatives is evaluated and the selection can be done.

A Data Collection System (DCS) mission is introduced herein, as illustrative example, taking into account cost and performance (excluding risk and schedule as effectiveness drivers).

4 Stakeholder and Requirement Analysis

The section outlines a simple stakeholder and requirement analysis approach. Time spent doing these analyses should match project type and complexity.

The first step is to identify project stakeholders. To be classified as a stakeholder, the person or group must have some interest or level of influence that can impact the project [7]. Stakeholder interests must be understood and so are the potential project impacts if a need is not met. Figure 2 depicts an example of this high-level analysis.



Stakeholder (score)	**Interests (value attributes)**	
	Performance	**Cost**
User	Availability (5%)	Maintenance (5%)
Sponsor	Sustainability (10%)	Elements (70%)
Program manager	Responsiveness (3%) …	Development Process (5%)
⋮	(10%)	(10%)
Operators	Operation easiness (10%)	Operation (5%)
Total	100%	100%

Figure 2. Stakeholder context diagram and interests for Data Collection System (DCS)

The second step of the method is to identify the stakeholders' interests and the relative importance for each one. To accomplish this stage, stakeholders should be listed on a table or spreadsheet with their key interests and relative importance in terms of cost, performance, risk and schedule. Special attention must be paid to outline multiple interests, particularly those that are overt and hidden in relation to project objectives. It is important to keep in mind that identifying interests is done with stakeholders' perspective in mind, not your own.

Requirements largely describe aspects of the problem to be solved and constraints on the solution [1]. Requirement analysis reflect sometimes conflicting interests of a given set of system’s stakeholders.

Many authors list sources of stakeholder requirements. Stevens et al. [8] provides a list of sources of users requirements and Pugh [5], a set of additional sources of stakeholder requirements.

Requirements analysis is conducted iteratively with functional analysis to optimize performance requirements for the identified functions, and to verify that the elaboratred solutions can satisfy stakeholder requirements.

The requirements refinement loop assures that technical requirements maps the stakeholder values, assumptions and goals.

5 Architecture Elements Definition, Key Trades Options, and Decision Drivers for each Stakeholder Value

The main objective of the integrated mission architecture trade off process is to integrate stakeholder analysis with architecture concept definition. This is carried out using decision drivers associated with architecture elements and stakeholder values, as shown in Table 1.

Table 1. Relationships among architecture elements options, stakeholder value attributes and cost, performance drivers associated with (DCS)

Architecture Elements and Key trades options		**Stakeholder value attributes (interests)**	**Decision drivers**
Mission	Space processing x ground processing	Maintenance price	Processing (cost)
		Operation price	Mission operators (cost)
		Availability	Time of transmit (performance) Message size (performance)
	Level of autonomy	Maintenance price	Infrastructure (cost)
		Operation price	Control operators (cost) N° of control stations (cost)
		Operation easiness	N of manoeuvres (performance)
Orbit / Constellation	Number of spacecrafts and orbit plans	Maintenance price	Infrastructure (cost)
		Operation price	Control operators (cost)
		Elements price (+1)	N° of spacecrafts (cost) N° of ground stations (cost) N° of control stations (cost)
		Availability	N° of spacecrafts (cost) Revisit time (performance) Interval of collect (performance) Interval of transmit (performance)
		Operation easiness	N° of spacecrafts (cost) N° of manoeuvres (performance)
		Sustainability	Funding constrains (performance)
Payload	BER / Mass	Element price	Payload mass (cost)
		Develop. process price	N° of employees (cost)
		Availability	Data rate (performance)
⋮		⋮	⋮

The architecture elements definition models a solution to the problem described in the requirements that comes from the stakeholder analysis (Figure 2). The terminology and concepts used to describe architectures differ from those used for the requirements [1]. Architecture deals with elements, which compose the system concept, capture and reflect the key desired properties (effectiveness) of the solution under elaboration. System (decision) drivers are the main mission parameters or characteristics which influence performance, cost, risk or schedule and which the user or designer can control [3].

In the context of requirements, architectural modelling has to satisfy the roles of supporting fast trade-off analyses about requirements' feasibility and stakeholder interests via architectural key elements options.

6 Mission Architecture Alternatives Assessment

Table 2 shows how to transfer the stakeholder analysis (interests and importance from Figure 1) results to the decision drivers (from Table 1). In this way, it is possible to translate the stakeholder preferences through the cost, risk, schedule and performance drivers inside the architecture trade off process.

Table 2. Transfering of stakeholder values importance to decision drivers for DCS

Stakeholder values Fig. 1 (cost)	**Decision drivers from Table 1 (cost)**	**Stakeholder values Fig 1 (performance)**	**Decision drivers from Table 1 (performance)**
Maintenance (10%)	Processing (3%) Infrastructure (7%)	Sustainability (30%)	Funding constrains (30%)
Elements (70%)	N° of spacecrafts (?) N° gr. stations (5%) N° contr. stations (5%) Payload mass (20%) Bus mass (30%) Launch (10%)	Availability (40%)	Time of transmit (5%) Message size (5%) Revisit time (10%) Interval of collect (5%) Interval of transmit (5%) Data rate (10%)
Dev. process (5%)	N° of employees (5%)	⋮	
⋮			
Operation (5%)	Operators (5%)	Oper. easiness (10%)	N° of maneuvers (10%)
Total 100%	**Total 100%**	**Total 100%**	**Total 100%**

The evaluation is done through the relationship matrix presented in Figure 3, which is built by using the information from Tables 1 and 2. The matrix relationships are shown at the lines and columns crossing.

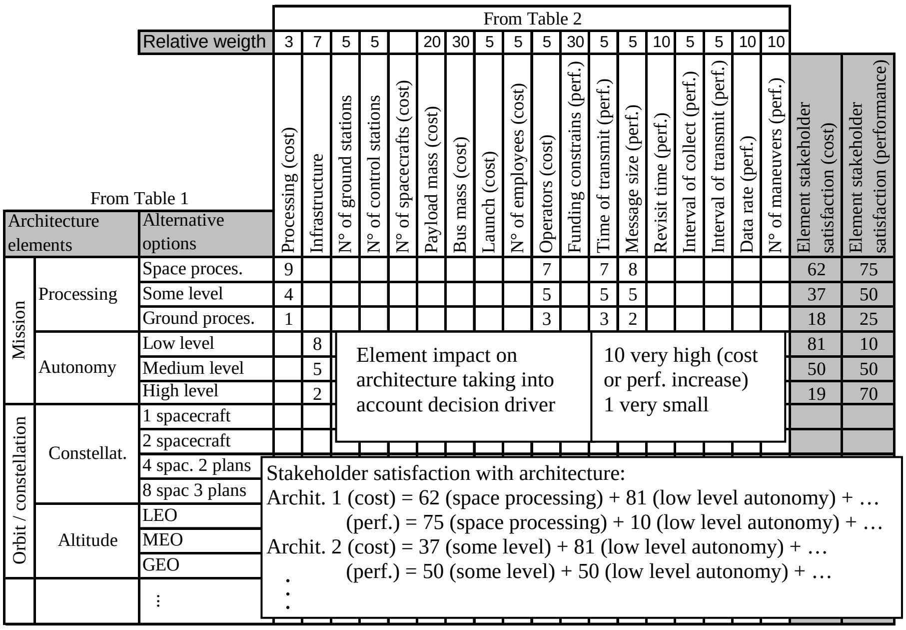


Figure 3. Mission architecture alternatives assessment for DCS

The last two columns are results obtained from the sum of products between relative weight and element impact on architecture taking into account the decision driver relationship established in Table 1. An evaluation of stakeholder satisfaction with architecture effectiveness is obtained trough sum of element results (one option for each architecture element).

The matrix presented in Figure 3 is just illustrative. More studies are necessary to modeling cost, performance, risk and schedule as decision drivers and improve the integrated mission architecture trade off.

7 Selection Rule Definition and Make a Selection

The selection rule criteria for systems differ significantly. In some cases, performance goals may be much more important than all others. Other projects may demand low costs, have an immutable schedule, or require minimization of some kinds of risks [6]. Then, the selection can be made taking into account the considerations as the explained above.

The expected result from the integrated space mission architecture trade off process is to obtain a graph as shown in Figure 4 (DCS case with performance and cost as effectiveness parameters): the bent line represents the envelope of the currently available technology in terms of stakeholder satisfaction with cost and performance. The points above the line cannot be achieved with the current available technology i.e. they represent designs that are not feasible. The points inside the envelope are feasible, but are dominated by designs whose combined cost and performance lie on the envelope. Designs represented by points on the envelope are called stakeholder satisfaction effective (efficient or non-dominated) solutions.

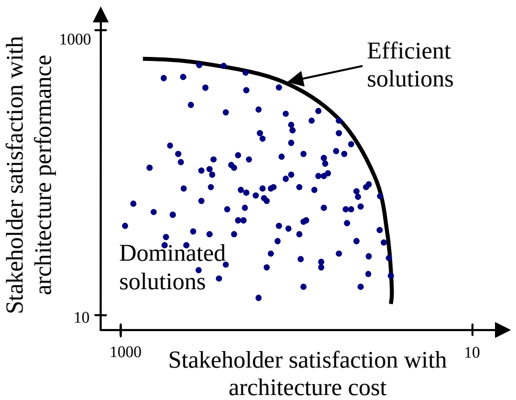


Figure 4. The Pareto frontier obtained from matrix results of Figure 2 (DCS)

Considering cost, performance, risk and schedule drivers, a four dimennsion evaluation is obtained and a efficient region is found by the proposed process.

8 Conclusions

Design methods present product development process in a systemized and organized way; however, the same do not occur with information and activities about the creation and evaluation of design alternatives. There are relatively few discussions about the trade off process in the literature [4].

Defining and using performance, cost, risk and schedule parameters as decision drivers and transfering to them the relative importance of stakeholder interests (values) in a trade off process may promote a new paradigm: a evaluation (through relationship matrix) of the architectutre effectiveness through the value that the stakeholder gives to performance, cost, risk and schedule. In this way, the stakeholder satisfaction with the system effectiveness becomes more important in the management decisions.

Thus proposal presented in this paper provides a means for innovating the mission design process by interconnecting stakeholder needs, requirement analysis, concept exploration and decision drivers in order to capture in trade off process the value given by stakeholders to the architecture performance, cost, risk and schedule. The paper proposes a subtle but closer to reality paradigm shift: trade the importance stakeholders give to performance, cost, risk and schedule attributes rather then those attributes themselves!

9 References

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